PROGRESS REPORT

PR 91570-510-10

For the Period of April 1, 1964, through April 30, 1964

DEVELOPMENT OF A HYDROGEN-OXYGEN SPACE POWER SUPPLY SYSTEM

NASA Contract NAS 3-2787

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INTRODUCTION

This report is issued to comply with the requirements of NASA Contract, NAS 3-2787, and to report the work accomplished during the period 1 April through 30 April 1964. The objectives of this program are to conduct engineering studies, design, fabrication and test work culminating in the design of an auxiliary power generation unit.

This contract, NAS 3-2787, is a continuation of NASA Contract NAS 3-2550.

PROGRAM SCHEDULE

The program schedule shown in Fig. 1 has been revised to reflect changes in the program plans resulting from a technical review meeting between NASA and Vickers Inc. on January 16 and 17, 1964. Component development and endurance testing will be extended through July, 1964. Flight system design work will continue to be deferred until additional development and endurance testing have been accomplished.

FLIGHT TYPE POWER DESIGN

No work was scheduled during this reporting period on the flight type power system design because of technical direction from the NASA Technical Program Manager.

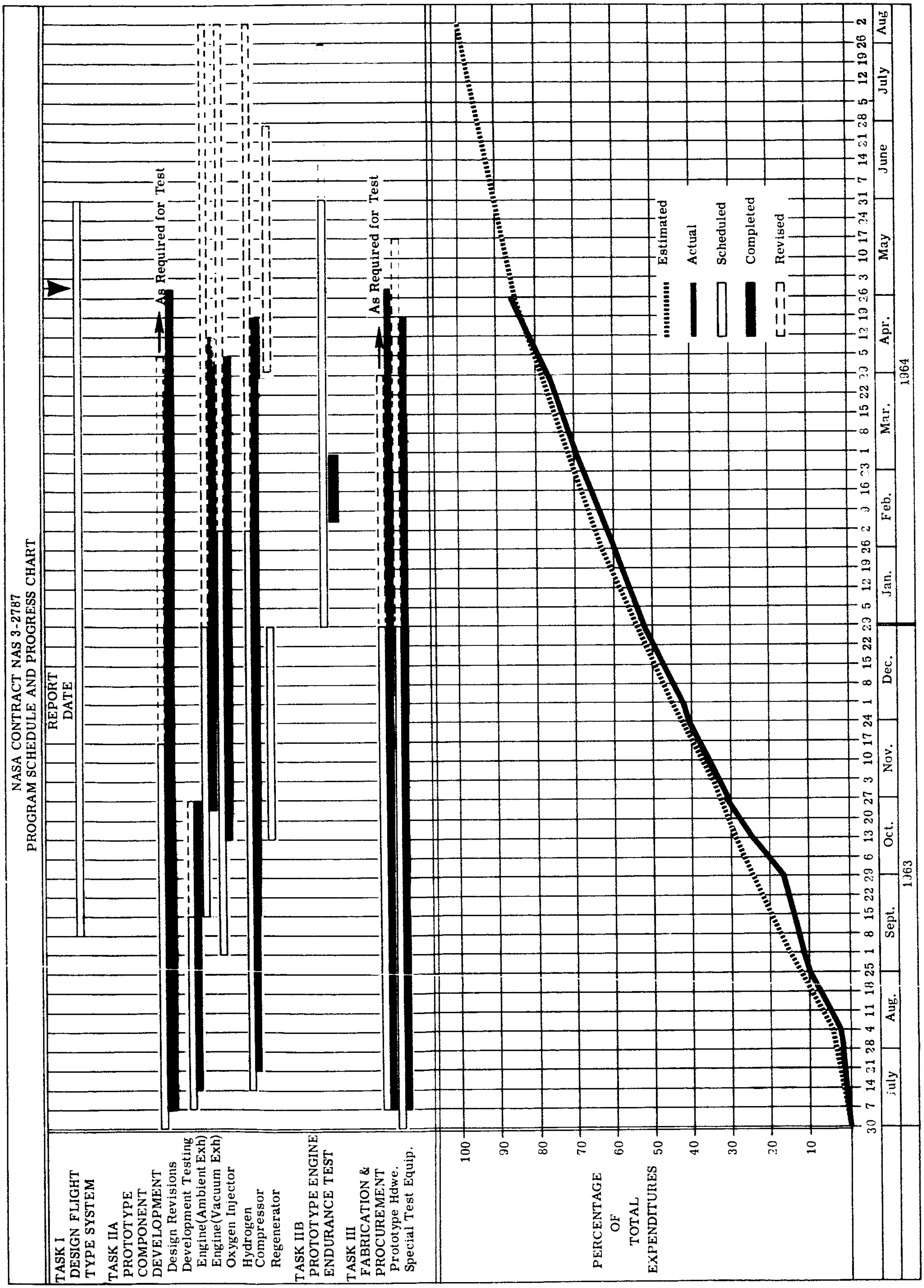

NASA CONTRACT NAS 3-2787
PROGRAM SCHEDULE AND PROGRESS CHART
REPORT DATE
TASK I
DESIGN FLIGHT TYPE SYSTEM
TASK IIA
PROTOTYPE COMPONENT DEVELOPMENT
Design Revisions
Development Testing
Engine(Ambient Exh)
Engine(Vacuum Exh)
Oxygen Injector
Hydrogen Compressor
Regenerator
TASK IIB
PROTOTYPE ENGINE ENDURANCE TEST
TASK III
FABRICATION & PROCUREMENT
Prototype Hdwe.
Special Test Equip.
As Required for Test
As Required for Test
PERCENTAGE OF TOTAL EXPENDITURES
100
90
80
70
60
50
40
30
20
10
Estimated
Actual
Scheduled
Completed
Revised
30 7 14 21 28 4 11 18 25 1 8 15 22 29 6 13 20 27 3 10 17 24 1 8 15 22 29 5 12 19 26 2 9 16 23 1 8 15 22 29 5 12 19 26 3 10 17 24 31 7 14 21 28 5 12 19 26 2
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug
1963
1964

Fig. 1

PROTOTYPE COMPONENT DEVELOPMENT

Engine

Design and Fabrication

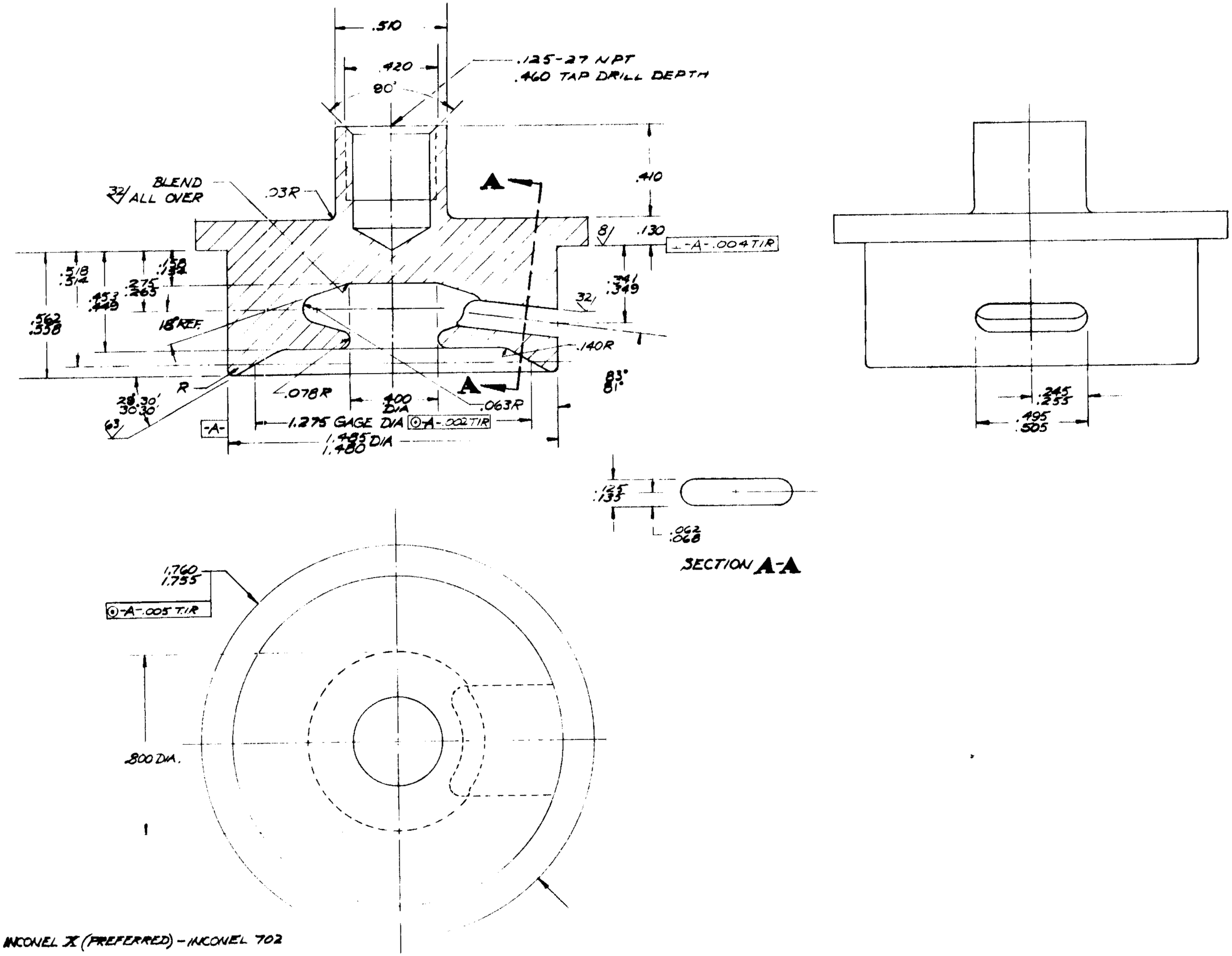
The following design and fabrication was accomplished during this reporting period:

1) A cylinder head insert with a mushroom shaped combustion chamber was designed and fabricated (see Fig. 2).
2) One cylinder jacket and cylinder were induction brazed together.
3) Existing cylinder head inserts were reworked for various different combustion shapes and means of holding catalyst pellets.
4) Fabrication of two new oxygen injector rocker shafts completed.
5) Three O_2 injector poppet blanks were finished for the new rocker arm.

Assembly

The following changes were made to the fifth buildup of Engine No. 1 (described in PR 91570-510-9) to evaluate the two and three-piece piston assembly configuration (in order of changes).

1) The original design three-piece piston assembly was removed from the engine because the dome securing the screw stretched and lost its installed torque.



Δ INCONEL X (PREFERRED) - INCONEL 702

Fig. 2 - Cylinder Head Insert with Mushroom Shaped Combustion Chamber

2) The two-piece piston assembly was installed with increased piston-to-cylinder bore clearance.

3) The above piston assembly was removed because the ring belt and rings appeared to have been running extremely hot. The compression rings took a set reducing the free end gap by 0.025 in. Fig. 3 shows a new ring to the left and a set ring to the right.

4) The three-piece piston assembly was reinstalled with the following changes.

   a) A 3/8 in. diameter dome securing stud bolt brazed to the inside of the ring housing.

   b) New compression rings with increased end gap clearance.

   c) Oil control ring turned upside down to evaluate oil consumption characteristics.

The fourth buildup of Engine No. 2 was completed and reached the endurance test stand on 4-30-64 for checkout of the new stand. The following were incorporated in this buildup:

1) A new cylinder and jacket assembly with Viton "O" rings.

2) A new X-609980 head ring without 10-mm catalyst ports.

3) A three-piece piston assembly with brazed dome securing screw. The No. 2 and No. 3 compression ring grooves reworked for three-piece rings.

4) A new crankshaft assembly with reground tapered hub spline for better gear mesh.

5) A new Elgiloy inner hydrogen valve spring for increased operating temperature.

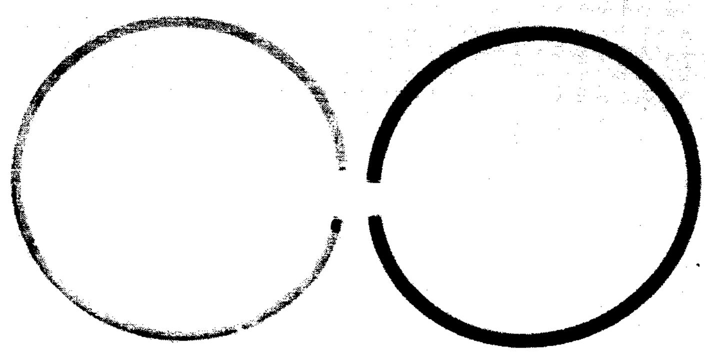


Fig. 3 - Engine Compression Rings,New Ring (left), Set Ring (right)

The oxygen injectors on both engines were reassembled with the redesign rocker arm (shown in Fig. 3 of PR 91570-510-8).

Performance Testing

A total of 9.9 hours hot running time and 8.3 hours cold motoring time was accumulated on the fifth buildup of Engine No. 1. All testing was accomplished on test stand No. 1. No endurance tests were run this month.

Representative test data are shown in Table I. Cylinder pressure - time traces are shown in the oscilloscope photographs of Figs. 5 through 12.

A set of standard operating conditions were defined in a telephone discussion with the NASA program manager. These standard conditions are listed in Table II. Runs marked with an asterisk in Table I have used this standard timing. Desired power levels have not been achievable with standard timing at the present clearance volume of 7-9% of displacement. A clearance volume of 12-14% may be needed at the present hydrogen inlet pressure and mixture ratio to achieve the desired 3 hp at 4000 rpm.

A series of experiments were made during performance tests to determine the causes of the hydrogen flow variations mentioned in PR 91570-510-9. Since the large seating diameter valve of the dual concentric hydrogen valve system has an opening pressure of only 350 psi, it was thought to be blowing open during that portion of the cycle in which it alone accomplishes the sealing. To check on this, the valve opening sequence was reversed, with the small head, hollow stem valve opening first. No change in trace appearance or hydrogen flow could be detected (see entries 1 and 2 of Table I. Several runs were made at an inlet pressure of 250 psi with the normal hydrogen valve arrangement (see entries 9, 10, 13, and 14 of Table I). Power and SPC was proportionately poorer, which indicated that no malfunction of the hydrogen flow had occurred at 300 psi inlet pressure.

The cylinder head of Fig. 2, page 5, of PR 91570-510-8, was found to direct oxygen flow very forcibly against the piston dome, causing erosion and extreme local heating. The appearance of the piston dome after a hot run can be seen in Fig. 4. This dome was modified to provide a shallower channel with slightly more clearance volume. Two timings were tried (see Table II). These tests are shown as entries 1 through 5 of Table I and in Figs. 5 and 6. An injector nozzle using three 0.017 in. orifices was used. Severe detonation and delayed combustion was experienced in top center operation with this nozzle, and a very high oxygen pressure was necessary. All of these tests were terminated by a failure of the upper cylinder "O" ring resulting in coolant leakage.

An injector nozzle using a single 0.028 in. angled orifice was tried, with even worse results; the engine would not run at all on a vacuum and misfired badly with exhaust back pressure (see entry 6, Table I). In all cases the extremely high oxygen inlet pressure did not show up as thermal compression as has been observed in the past.

The three piece piston with new narrow rings was broken-in by motoring for four hours and the engine was calibrated on standard timing and at a higher power level, at 250 and 300 psi H_2 inlet pressure. The results are shown in Figs. 7 and 8, and in entries 7 through 14, Table I. The same injector and cylinder head were used. Inlet hydrogen was heated to 500°F in these runs.

The channel head designed for the old engine was mounted and used for the runs shown as entries 15 through 18 of Table I and in

Fig. 9. It was thought that this head would give more power due to a greater clearance volume, although the combustion chamber was irregular in shape since the piston dome did not match this power and BSPC were poor at both timings.

Hydrogen inlet was retarded to O° (TDC) and another injector using a larger 0.032 in diameter seat and a calcium fluoride plated oxygen injector poppet was used in the tests of entries 19 and 20. The P-T trace is shown in Fig. 10. Although this injector poppet showed no guide area wear in two hours of injector test stand operation with hot (300°F) oxygen it quickly wore down to the base metal in 35 minutes of hot engine operation. Performance, however, was not impaired and leakage remained negligible. No improvement due to retarded H_2 opening could be detected.

The mushroom cylinder head was used in the runs shown as entries 21 through 24 of Table I. Two different injectors were tried, giving an oxygen swirl in opposite directions from each other. Performance was good for this power level, and operation on a low back pressure of 50 mm Hg was possible with little or no late combustion. Pressure time traces are shown in Figs. 11, 12, and the mushroom head after the runs of April 29 is shown in Figs. 13 and 14.

A failure of the top "O" ring sealing the water jacket to the cylinder walls occurred immediately after shutdown unless the engine was very gradually cooled to a head temperature of 600°F - 800°F before shutting off oxygen flow. The top cylinder wall gasket also failed twice. These malfunctions hampered the gathering of data on tests run this month and it is felt that the new design cylinder and pistons have not yet been adequately evaluated.

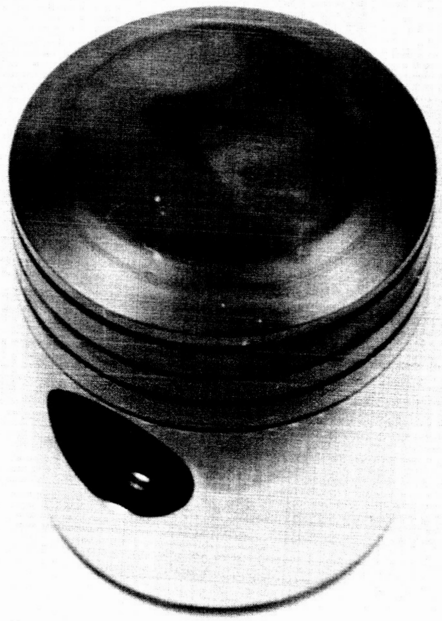


Fig. 4 - Piston After April 10 runs (Note Piston Dome Erosion)

TABLE I

ENGINE PERFORMANCE DATA - APRIL 1964

Entry	Time Date	Time Hour	Oper. Cond. No.	H_2 Inlet Temp °F	H_2 Inlet Press. psig	O_2 Inlet Press. psig	Speed rpm	BMEP psi	Power hp	BSPC lb/hp-hr	O/F lb/lb	% Heat Rejected	Exhaust Press. mm Hg	Cyl. Hd. Temp °F
1	4-10	10:00	1	90	300	680	3997	124	3.39	2.12	1.27	83	180	1370
2	4-10	10:05	1	90	300	580	3007	130	2.69	2.15	1.40	96	150	1470
3	4-13	4:22	2	90	300	800	4020	102	2.82	2.28	1.28	98	450	1540
4	4-13	4:35	2	90	300	710	2990	116	2.39	2.25	1.51	106	250	1580
*5	4-14	2:36	3	100	300	465	2990	74	1.53	2.48	1.30	129	370	1475
6	4-15	4:08	4	88	300	590	2960	80	1.63	3.48	1.05	168	760	1570
7	4-21	3:44	5	520	300	955	4000	99	2.72	1.97	1.43	86	350	1430
8	4-21	3:56	5	500	300	900	3010	107	2.20	2.02	1.60	113	350	1460
9	4-21	4:05	5	500	250	1000	4000	84	2.31	2.08	1.96	106	350	1435
10	4-21	4:12	5	500	250	840	3000	90	1.86	2.12	2.01	131	300	1520
*11	4-22	2:37	6	500	300	760	4010	66	1.80	2.24	1.53	114	250	1500
*12	4-22	2:41	6	510	300	710	3000	60	1.23	2.80	1.73	167	220	1540
*13	4-22	2:50	6	490	250	850	3990	60	1.64	2.34	2.05	133	220	1540
*14	4-22	2:55	6	480	250	750	2990	48	0.98	3.16	2.24	210	200	1550
*15	4-23	1:38	7	500	300	600	3000	83	1.71	2.75	0.73	100	200	1470
*16	4-23	1:47	7	520	300	730	4020	78	2.15	2.66	0.85	88	270	1540
17	4-24	9:22	8	520	300	740	4000	82	2.26	2.48	0.89	95	250	1565
18	4-24	9:39	8	530	300	650	3010	87	1.80	2.71	0.80	104	240	1555
19	4-27	2:01	9	490	300	660	4020	104	2.88	2.00	0.92	68	270	1480
20	4-27	2:06	9	510	300	570	2990	105	2.15	2.31	0.93	86	250	1500
*21	4-29	5:50	10	490	300	1000	3020	86	1.78	2.08	1.16	89	50	1505
*22	4-29	5:56	10	490	300	1050	4000	78	2.15	2.10	1.03	76	50	1460
*23	4-30	4:03	11	480	300	650	4020	75	2.06	2.44	0.88	84	50	1550
*24	4-30	4:10	11	520	300	600	2990	86	1.75	2.60	0.81	89	50	1515

*Standard Timing

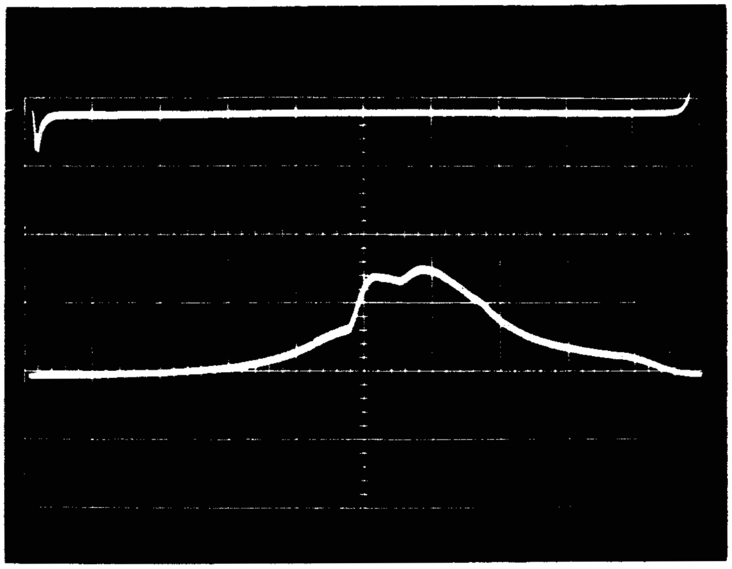


Fig. 5
4-13-64 4:22 p. m.

4000 rpm
450 mm H_g back pressure
Ambient H_2 inlet temp.
2. 82 hp
BSPC = 2. 28 lb/hp hr.

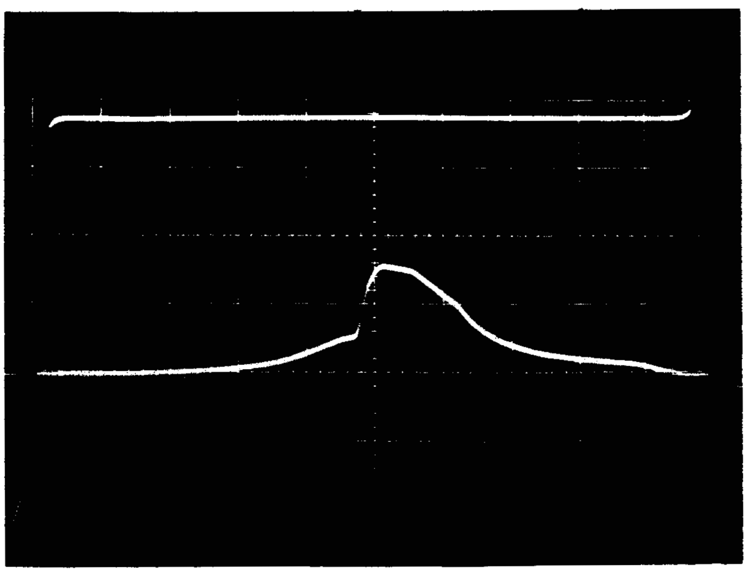


Fig. 6
4-14-64 2:36 p. m.

3000 rpm
Standard timing
Ambient H_2 inlet temp.
1. 63 hp
BSPC = 2. 48 lb/hp hr.

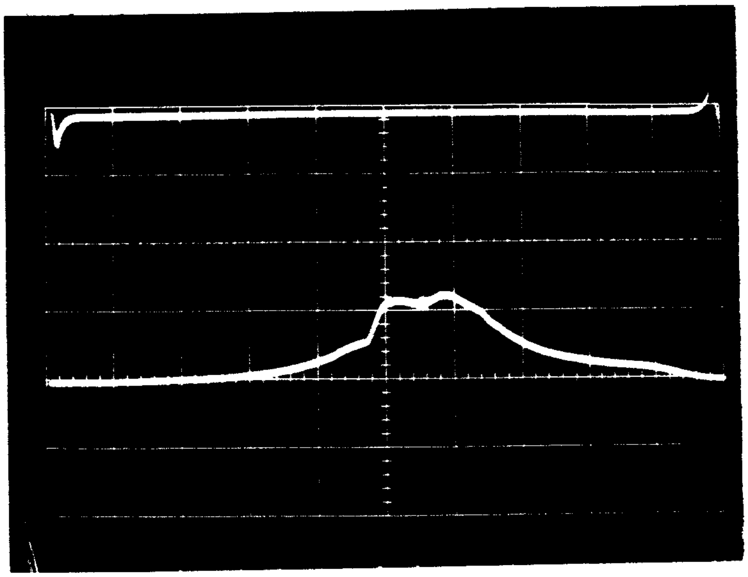


Fig. 7
4-21-64 4:05 p. m.

3000 rpm
250 psi inlet H_2 at 500°F.
2. 31 hp
BSPC = 2. 08 lb/hp hr.

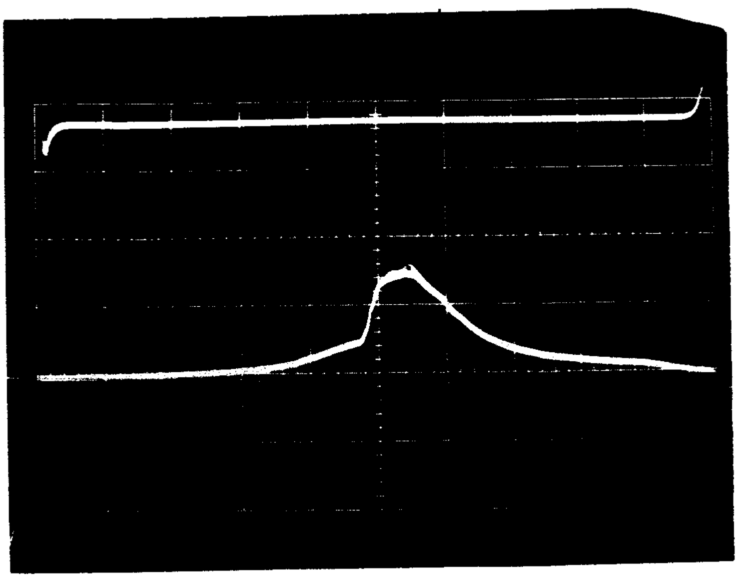


Fig. 8
4-22-64 2:37 p. m.

Standard timing
4000 rpm
1. 80 hp
BSPC - 2. 24 lb/hp hr.
Traces of late combustion are visible.

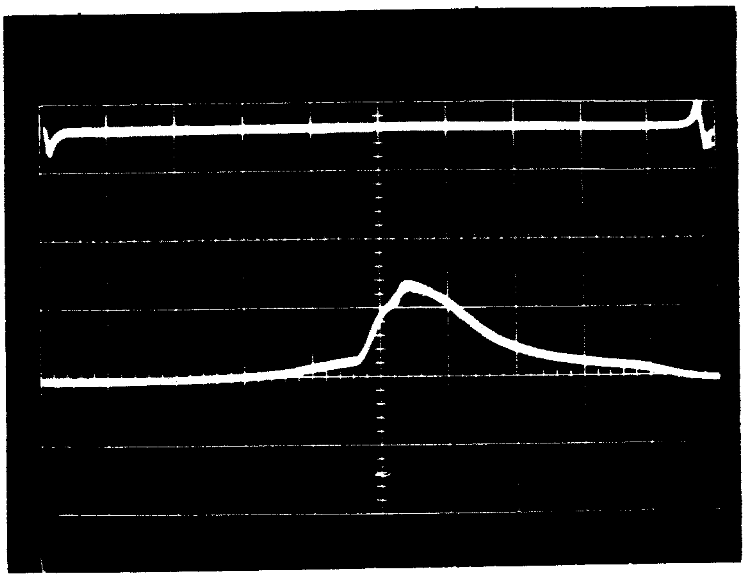


Fig. 9
4-24-64 9:39 a.m.

3000 rpm
1.80 hp
BSPC - 2.71 lb/hp hr.
Intermittent late combustion

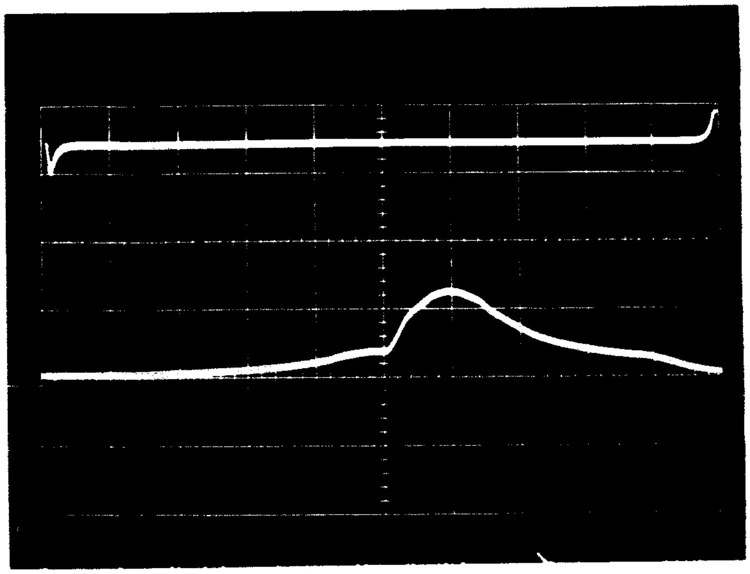


Fig. 10
4-27-64 2:01 p.m.

4000 rpm
2.88 hp
BSPC - 2.00 lb/hp hr.
Retarded H_2 admission.

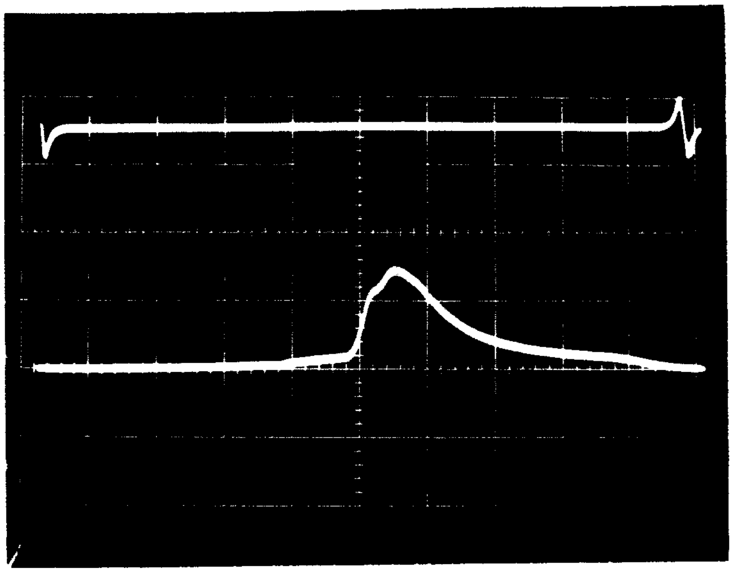


Fig. 11
4-29-64 5:56 p. m.

Standard timing
4000 rpm
2.15 hp
BSPC - 2.10 lb/hp hr.

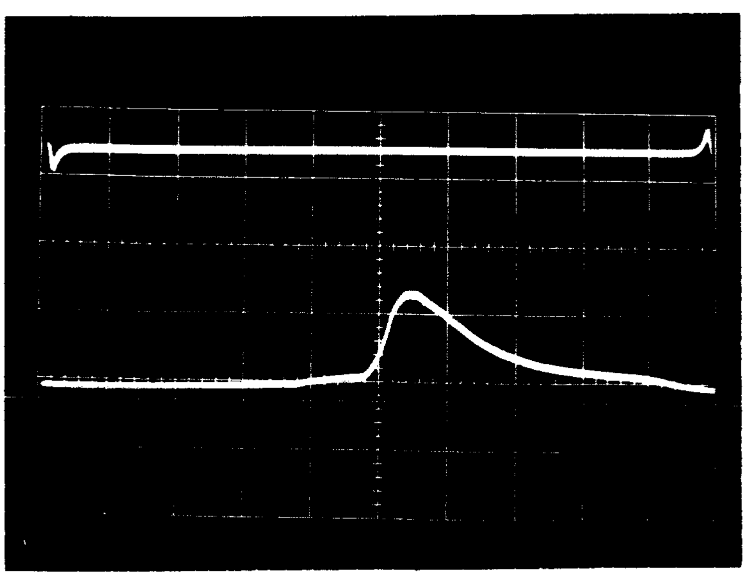


Fig. 12
4-30-64 4:10 p. m.

Standard timing
Mushroom head
3000 rpm
1.75 hp
BSPC = 2.60 lb/hp hr.

TABLE II

STANDARD OPERATING CONDITIONS

1. Hydrogen Timing 10° BTDC - 20° ATDC
   Oxygen Timing 0° (TDC) - 40° ATDC

2. 300 mm exhaust back pressure

3. Hydrogen at 300 psig, 500°F at inlet

4. Oxygen - injector sized to give an O/F of 1.25 at 600 psig

5. Cylinder head 1500 - 1700°F

6. Cylinder wall temperature 400°F in cooled portion

7. Oil temperature 170 - 200°F

8. Coolant temperature 250 - 280°F

9. Clearance volume sized to give a power of approximately
   30 hp at 4000 rpm, 2.3 - 2.5 hp at 3000 rpm.

TABLE III

ENGINE OPERATING CONDITIONS

1. Hydrogen Timing 10° BTDC to 35° ATDC
   Oxygen Timing 15° ATDC to 55° ATDC
   8% clearance volume
   Oxygen injector nozzle used three 0.017 in. holes
   2-piece reworked piston
   Reversed hydrogen valve operating sequence

2. Same as No. 1 except for normal hydrogen valves, reworked cylinder head. (9% clearance volume).

3. Same as No. 2 except that standard timing was used (See Table II).

4. Timing as in No. 1 above. Singe hole 0.028 in. injector orifice used.

5. Three piece piston with new narrow one-piece rings, upside down oil ring. Otherwise same as No. 4.

6. Same as No. 5 except for standard timing.

7. Same as No. 6 except that the old channel head designed for use on the brazed cylinder assemblies was used.

8. Same as No. 7 except for timing:

   Hydrogen 10° BTDC to 20° ATDC
   Oxygen 5 ATDC to 45° ATDC

9. Hydrogen Timing 0° (TDC) to 35° ATDC
   Oxygen Timing 15° ATDC to 55° ATDC
   Oxygen injector used single 0.032 in. orifice and calcium fluoride plated poppet.

10. Standard timing. Mushroom head 9% clearance volume. 0.028 in. injector nozzle with unplated poppet, as used in Nos. 4 through 8.

11. Same as No. 10, except that the 0.032 in. injector nozzle and calcium fluoride plated poppet of No. 9 were used.

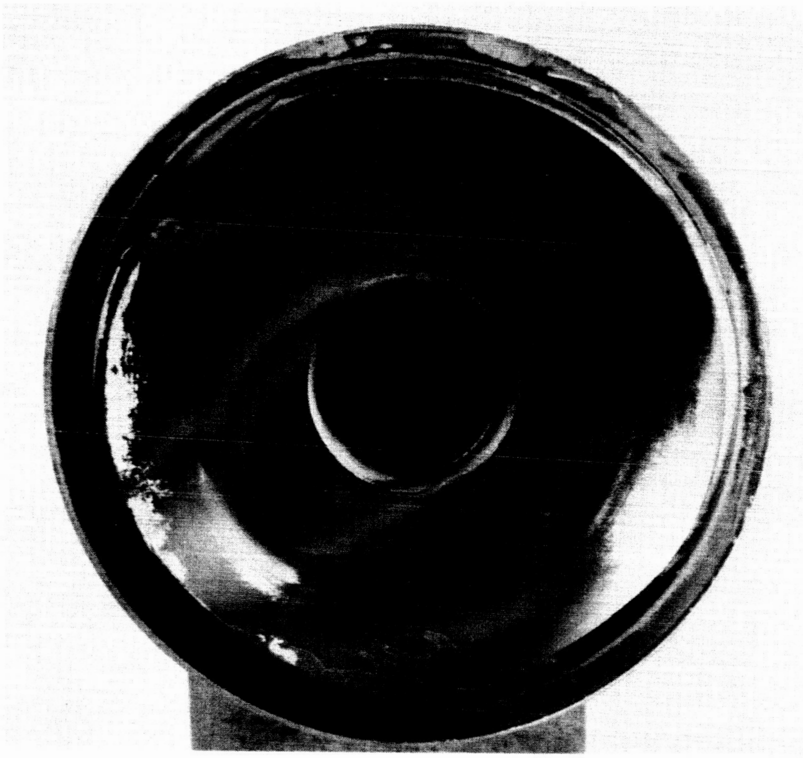


Fig. 13 - Mushroom Combustion Chamber (bottom view)

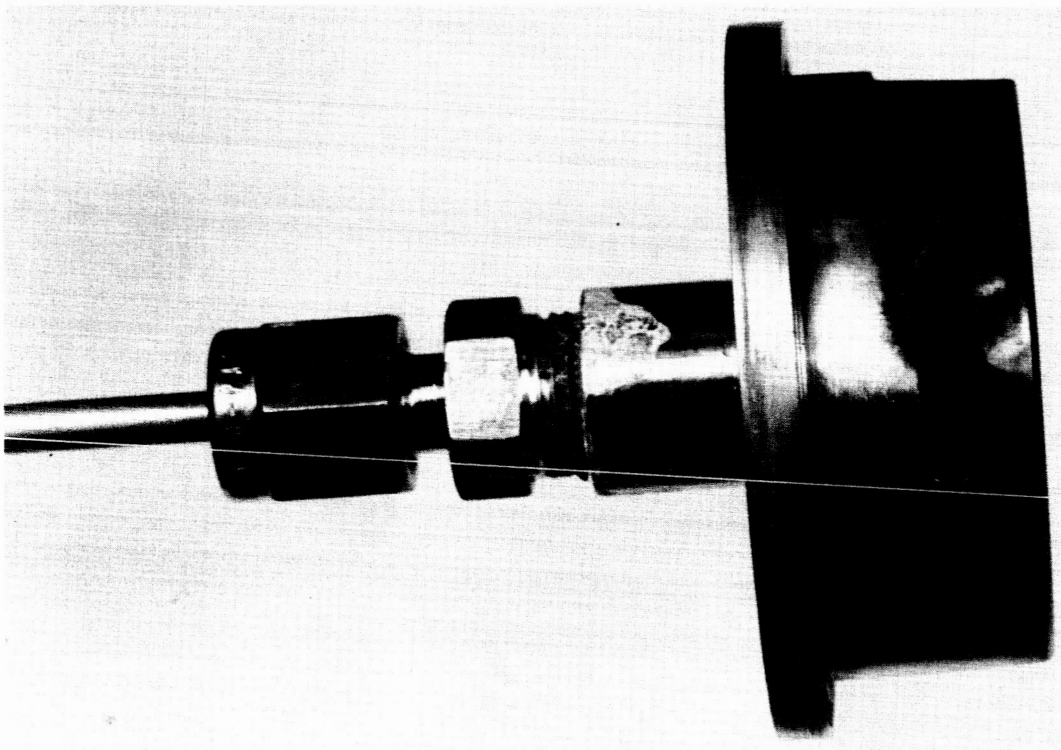


Fig. 14 - Mushroom Combustion Chamber - Entrance to Gas Passage

Oxygen Injector Performance

The new oxygen injector rocker arm design was evaluated on the injector test stand prior to use on the engine. Thus far the rocker appears to function as intended both on the injector stand and on the engine. The injector flow continues to increase with ΔP over the pressure range tested, as shown in Fig. 15.

Some erratic injector performance has been experienced using the split injector drive design. To eliminate this problem it was necessary to adjust valve lift to compensate for the crankcase casting deflections which result from torquing the cam cover and rocker shaft bearing screws.

A calcium fluoride coated poppet was evaluated by running it for two hours on the injector test stand with 300°F oxygen and also by running it for 35 minutes on the engine. The guide surface showed no wear after the stand test run, but it appeared to be worn away after the 18 minute engine run.

Compressor

Design and Fabrication

No design work was done during this reporting period. The fabrication of a lightweight first stage inlet valve was completed.

Assembly

No assembly work was performed during this reporting period.

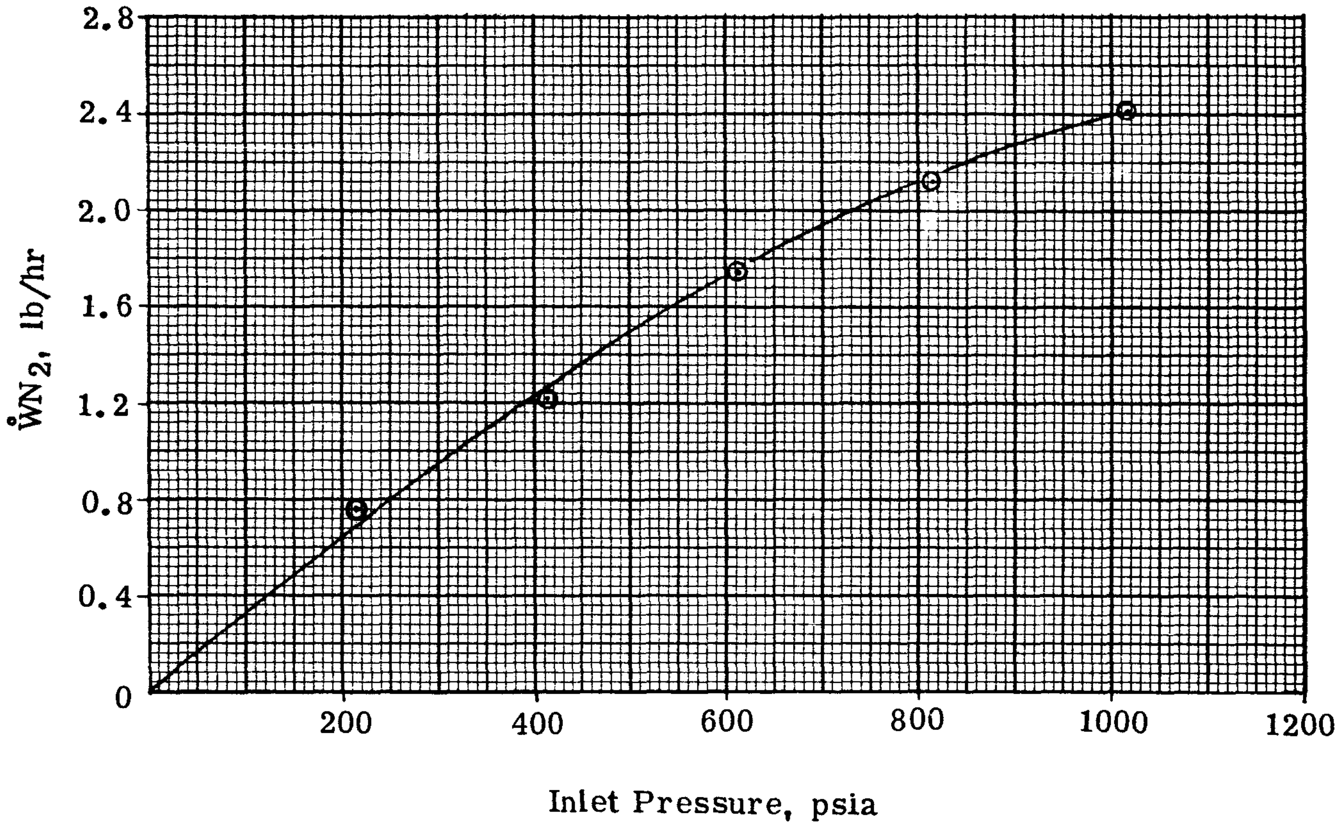


Fig. 15 - $\mathring{W}N_2$ versus Injector Inlet Pressure on Injector Test Stand

Performance Testing

No. 2 compressor was tested this month.

Test objectives were:

1) To determine the performance of a new piston design shown on page 26 of Progress Report 91570-510-7.

2) Endurance testing of a new metal bellows.

3) To determine 1st stage valve characteristics.

4) Preliminary compressor calibration.

The new piston design was tested from 0-4000 rpm, and an inlet gas temperature range of -200°F to +80°F. The design objectives were met with this new design. The effect of cylinder temperature change on the sealing lip was eliminated and the piston now works freely and is pressure tight in the operating temperature range.

Various 1st stage valving modifications were tested while running the new piston design. Fig. 16 shows $\eta v/CF$ versus speed for five 1st stage (only) compressor runs. A summary of the test and valve conditions for each run is shown in Table IV. The high speed end of each curve is the point at which valve floating became critical. Flow dropped off sharply when the speed was increased beyond this point.

Fig. 17 is a plot of $\dot{W}_{H_2}$ versus speed for the same five (5) test runs. The $\dot{W}_{H2}$'s were calculated for the maximum target (37°R to 60°R) inlet temperature of 60°R using the η_v reduced from the test

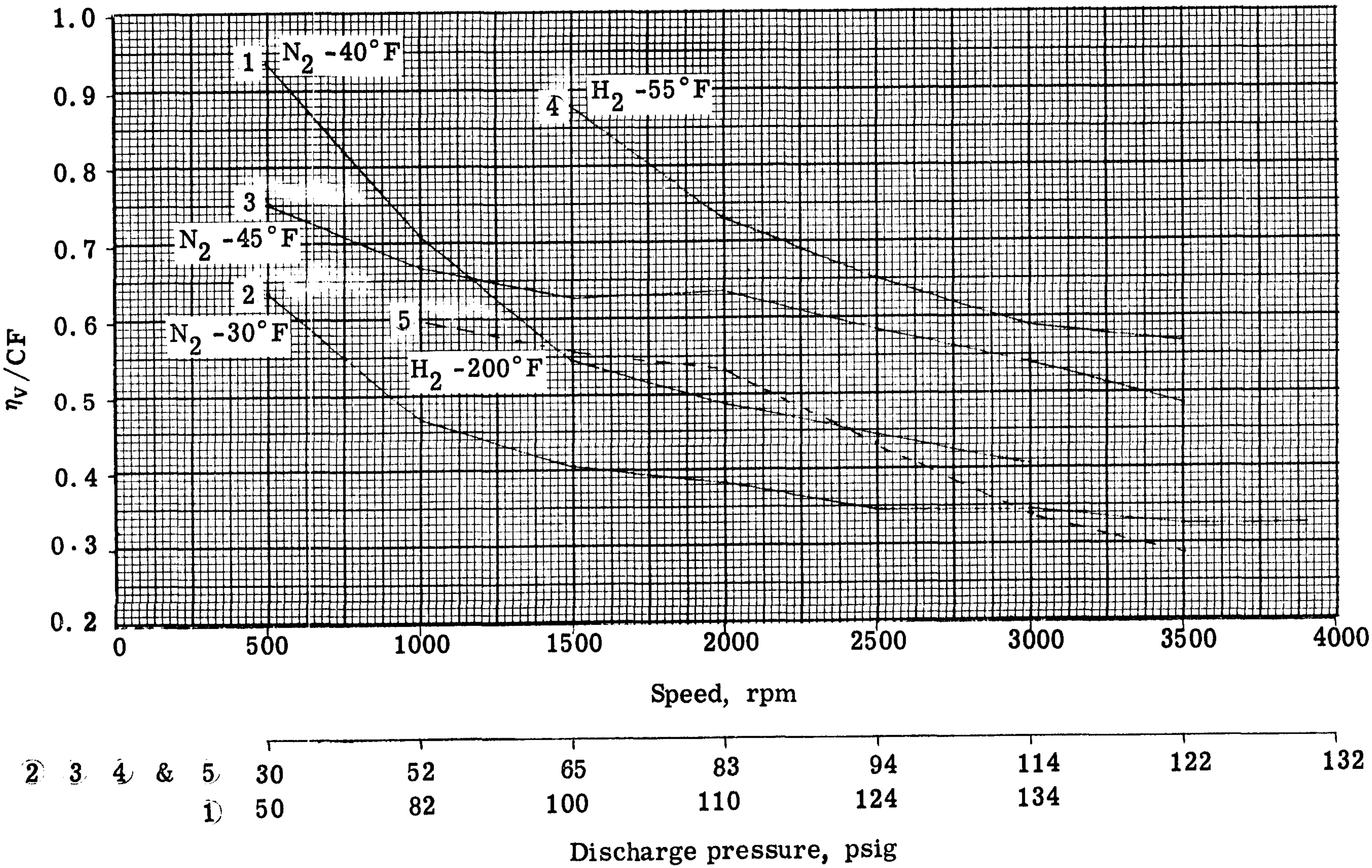


Fig. 16 - First Stage Compressor η_v/CF versus Speed

TABLE IV

	Curve No.				
	1	2	3	4	5
Run No.	20	23	24	25	26
Run Date, 1964	4/20	4/22	4/27	4/28	4/29
Inlet Press., psia	19.8	19.5	19.65	19.65	19.65
Inlet Temp., °F	-40	-30 to -35	-45 to -60	-55	-200
Outlet Press., psia					
Min	65	45	45	48	48
Max	150	150	135	140	140
Gas	N_2	N_2	N_2	H_2	H_2
Inlet Valve Material	AL	AL	S.S*	S.S	S.S
Inlet Valve Cracking Press., Δpsi	1	1	1	1	1
Outlet Valve Cracking Press., Δpsi	3	70	6	6	6
Critical Valve Floating, rpm	2800-3000	3800	3500	3500	2500

* Stainless Steel

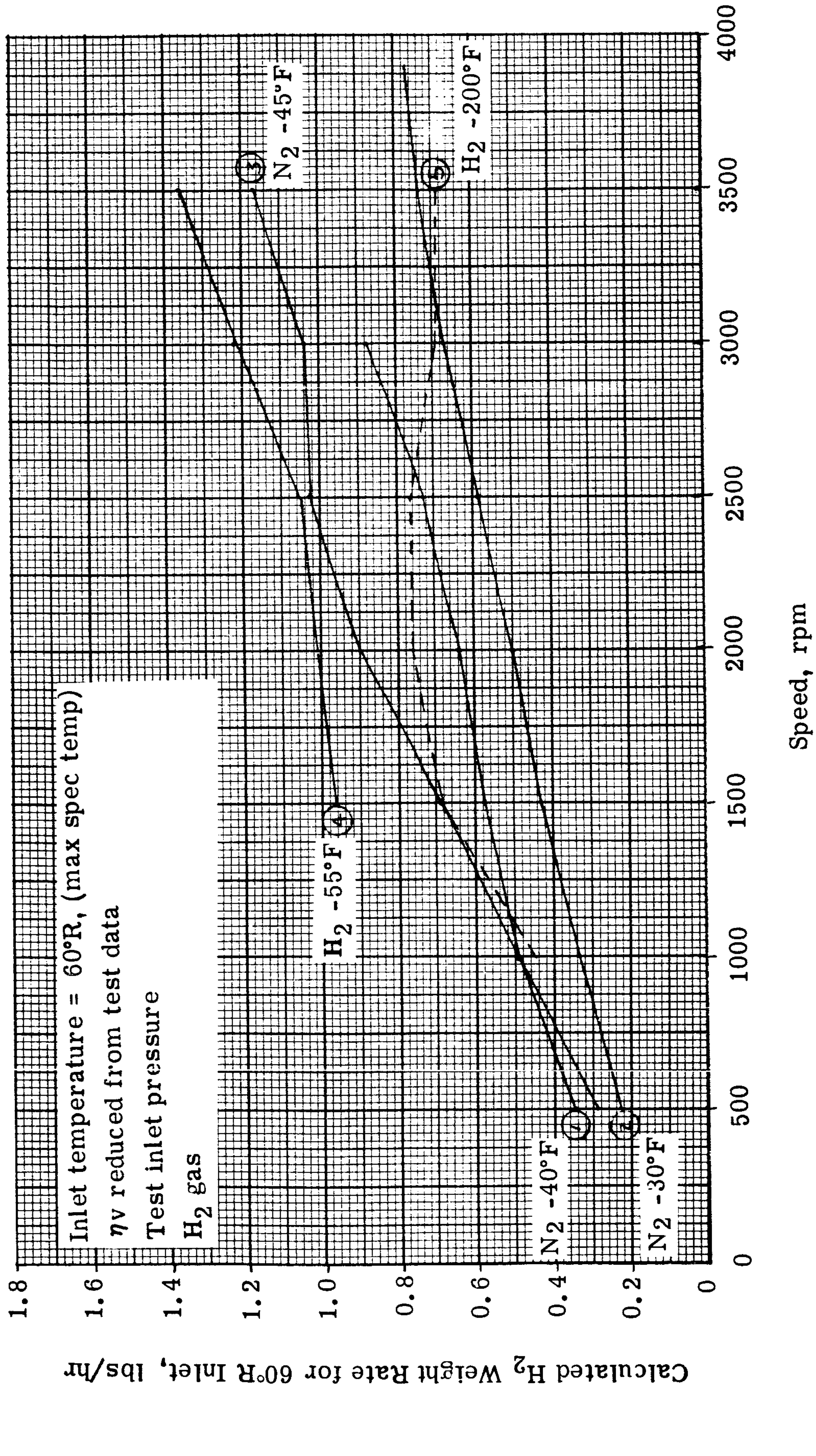


Fig. 17 - Calculated $\dot{W}$ versus Speed

runs. The flow was not corrected to the minimum target inlet pressure of 15 psia. This would not have been valid because inlet valve pressure drop loss reduces η_v directly as inlet pressure is dropped.

Considering that all the curves in Fig. 16 are fairly high at the low speed end and that they drop off with speed increase, indicates that the piston sealing lip is doing its job, since effect of piston leakage becomes less as speed is increased. The piston has excellent static suction and compression when tested by placing the palm of the hand over the open end of the cylinder, and the seating lip retained its flexibility and contact with the cylinder when it was cooled in LN_2.

A comparison of curves 1 and 2 shows that the speed of critical valve floating was increased by about 1000 rpm by increasing the discharge cracking pressure (increasing the spring force) from 3 to 70 psi. The increased speed was accomplished at the expense of increased throttling loss and no net increase in flow resulted. This comparison and the drop off with speed of $\eta v/CF$ indicates that the discharge valve seat diameter should be increased. The ratio of seat diameter to moving mass should be increased as much as possible when this is done.

A comparison of curves 3 and 4 shows that at approximately the same operating condition the $\eta v/CF$ and equivalent flow are considerably greater with H_2 than with N_2. This performance difference is due to the difference of valve throttling loss between the two gases. The magnitude of the difference, and the dropoff at high speed indicates that the valve areas are too small

A comparison of curves 4 and 5 shows that when H_2 inlet temperature was reduced from -55°F to -200°F the performance dropped greatly. This drop was much greater than could be attributed to increased throttling loss due to increased gas density. The 1st stage cylinder head was removed and cooled in LN_2 and it was found that the valve spring contracted sufficiently to allow the valve to fall open freely under its own weight. This reduced valve spring load with decreased temperature would account for poor performance at -200°F inlet temperature.

In progress report PR 91570-510-9, page 33, the failure of the metal bellows in No. 1 compressor was reported. The failure was not considered conclusive, because the bellows was slightly damaged before the test started. Since the compressor was not disassembled for 100 hours the time of the failure was unknown. Great attention was given to the bellows in the No. 2 compressor. The bellows was carefully pressure tested. Accurate data were kept on the daily cycling during the piston performance testing, and periodical pressure testing of the bellows was performed. During the 100 hour test on No. 1 compressor, 15×10^6 cycles were accumulated. This figure was chosen to be the target for No. 2 compressor bellows so that the bellows performance could be compared to the performance of the piston and the internal drive linkage that passed the 100 hour test.

After 5×10^6 cycles the bellows in the No. 2 compressor developed a small pinhole leak in the weld at the junction of the top two convolutions. Because of the two failures, and due to the expense and long fabrication time required, no further testing of this bellows design is planned for this program. For safety, a N_2 case purge will be used during H_2 compressor operation.

Summary

The current status of compressor development is summarized as follows:

1) **Piston-to-cylinder seal**
An effective piston-to-cylinder seal design has been developed and 100 hour life-demonstrated.

2) **Internal drive linkage**
An effective drive linkage with non lubricated bearings has been developed and 100 hour life-demonstrated. Principles that can be used in a flight design have been revealed. The metal bellows design tested with the drive linkage appears to be inadequate. More design and material study is required in this area.

3) **Valving**
Testing to date indicates that present valving is inadequate for high speed operation. The present 1st stage inlet valve spring design does not allow for efficient operation at both high and low temperature. Low temperature operation efficiency could be increased by increasing the spring load. Knowledge has been gained from testing which can be applied to the flight system compressor design. More detailed understanding, which might lead to efficiency improvement of the present valving, could be gained by monitoring cylinder pressure with a transducer and an oscilloscope. However, this type of testing is not justified unless a lower compressor operating speed is to be selected, since it has become apparent that a new valve design will be required for 4000 rpm operation.

4. Plans

Current plans are to run calibration tests to document performance with best present valving and to record in a logical order all information learned from the program so that it may be used to prepare a flight design.

Regenerator

Fabrication of test hardware parts is complete.

PROTOTYPE ENGINE ENDURANCE TEST

Setup of the endurance test facility is complete. Checkout will start during the first week of May, the operating procedures for the test stand are given in Appendix A.

RELIABILITY AND QUALITY ASSURANCE

General

There was one reliability milestone scheduled and completed during the month of April (see Fig. 18). This was a description of Vickers Inspection System (Appendix B).

Two meetings were held during the month between the NASA Western Operations office reliability and quality monitoring and Vickers Incorporated reliability personnel. A personal inspection of Vickers calibration control system was accomplished.

Instrumentation Control

The calibration control procedure submitted in the February Progress Report, PR 91570-510-8, is presently being implemented.

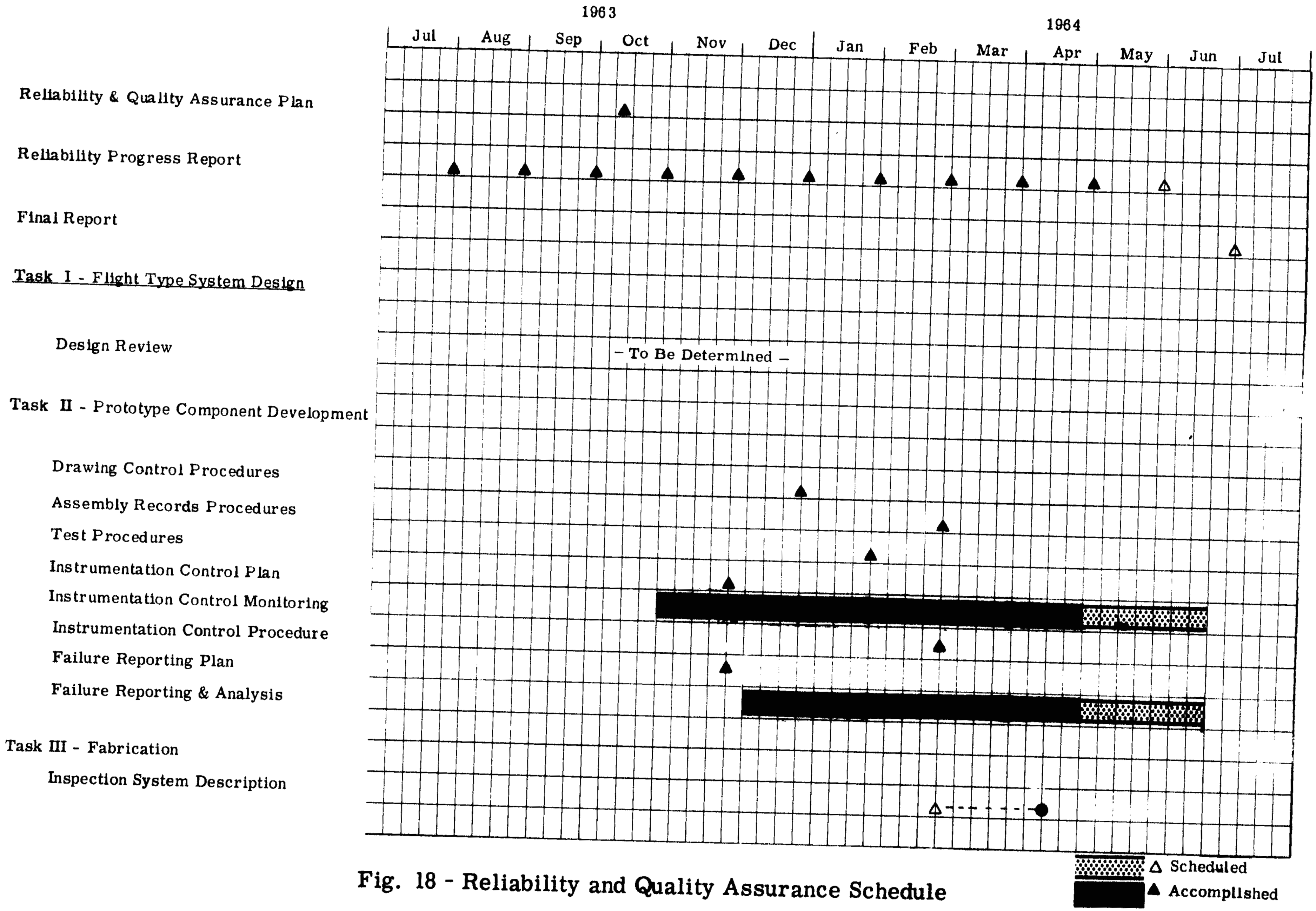


Fig. 18 - Reliability and Quality Assurance Schedule

All gauges except one ΔP gauge and the oscilloscope are now within the calibration frequencies. During the month the vacuum gauge was sent out for complete overhaul and recalibration because of an accumulation of moisture inside the gauge. This gauge was temporarily replaced by one of lesser accuracy and will be returned to the test stand during May. To prevent this from occurring in the future a silica gel disiccant will be used to soak up the moisture prior to admittance into the gauge.

Failure Reporting Analysis

Monitoring of all failures of the H_2-O_2 engine continued as described by the Vickers failure reporting plan (November Progress Report, Appendix A).

During the month two new modes of failure were recorded (see Appendix C). These failure modes are coded as follows:

Top-Cylinder to Cooling Jacket "O" Ring Failure (2F)
A number of silicon and Viton "A" "O" ring failures occured. These failures occured because the "O" rings were heated to above their operating temperature. By changing the combustion shape to reduce the top cylinder temperature, successful runs have been made using the Viton "A" "O" ring; however, the cooling jackets will be brazed to the cylinder to eliminate the "O" rings from the design.

Copper, Head to Cylinder Gasket (2G)
A number of head gasket failures occured during the month. The following corrective actions are being taken:

1) The seating surface of the cylinder is being modified.

2) Stainless steel gaskets are being fabricated.

3) The head bolts will be heat treated to a higher working stress.

Inspection System Description

A general description of Vickers quality assurance inspection system is presented in Appendix B. Some of Vickers methods described are: inspection planning; quality assurance records; drawing and change control; in-process inspection; final inspection and other processes employed throughout the fabrication of hardware.

This document is submitted as a supplement to a partial description of Vickers inspection system submitted in the Quality Assurance and Reliability Engineering Program Plan dated 30 September, 1963.

APPENDIX A

OPERATING PROCEDURE

OPERATING PROCEDURE

DYNAMOMETER STAND

1.0 INITIAL CONDITION

1.1 H_2 and O_2 pressure switches "Off".
1.2 H_2 and O_2 supply switches "Off".
1.3 H_2/N_2 and O_2/N_2 switches to "N_2".
1.4 Motor/Absorb switch to "Motor".
1.5 dc power switch "Off".
1.6 Dynamometer field control fully CCW.

2.0 STANDBY CONDITION

2.1 Turn the two circuit breakers inside closed equipment rack "On".
2.2 Turn the 440 VAC line switch located on west wall of control room "On".
2.3 Rotate the external circuit breaker control on closed equipment rack to "On". Note field current indication of 8 to 10 amps.

3.0 OPERATE CONDITION - MOTORING

3.1 Turn dc power switch "On" and note that the dc power lamp, the two N_2 lamps and the reset lamp come on.
3.2 Operate the reset switch momentarily and note that "Standby" lamp comes on and the two blowers start to operate.
3.3 Press standby push button on main console and note that "Standby" lamp comes on and the two blowers start to operate.

3.4 Press start push button on main console and note that "Run" lamp comes on and the 20 hp motor starts.

3.5 Slowly rotate the field current control CW land note that the motor/generator on the test bed begins to rotate. The field current control may now be adjusted for the desired rotational speed. When power is applied to the test stand from the H_2O_2 engine, the system automatically goes from the "Motoring" mode to the "Absorption" mode with an increase in speed of less than 400 rpm.

4.0 The setting of gas pressures and the operation of the lubrication system, the cooling system, the hydrogen heating system, and the vacuum system are so similar to present methods that they will not be covered here.

5.0 <u>SAFETY CONTROLS</u>

5.1 There are a total of six sensing devices that will operate the safety circuits automatically plus a "Panic" button to manually shut down the entire system. The system will remain off until the "Reset" switch is operated.

5.2 The activation of any of the safety controls causes the following conditions to exist.

5.2.1 H_2N_2 and O_2/N_2 valves revert to N_2 position, for engine purge, as indicated by amber pilot lamps. NOTE: The manual control switches should be returned to N_2 position prior to reset.

5.2.2 All power is removed from dynamometer and it reverts to the conditions existing at para. 3.1.

5.3 The safety devices incorporated in the system operate as follows and cause shutdown condition previously noted.

5.3.1 The two lubricant pressures are monitored by Barksdale pressure switches and the reduction of pressure below 20 psig or 250 psig respectively causes system shutdown.

5.3.2 Cylinder head temperature and coolant outlet temperature are sensed by thermocouples and are monitored by indicating meter relays. Increase of temperature above 1900°F for the cylinder head or 350°F for the coolant outlet will cause system shutdown. The indicating devices have the added feature of locking the pointer in the operate position until the reset switch is operated. This aids in isolating the problem area.

5.3.3 Dynamometer speed is indicated by an ac tachometer and is monitored by a O-50 VAC meter relay. This device acts as an overspeed control and is preset to shutdown system in the event of speeds exceeding 5000 rpm. This device also has holding contacts for maintaining its reading until reset.

5.3.4 A transistorized device for sensing engine failure has been incorporated in the safety control system and is switched in or out of operation by the position of the motor/absorb switch. For all motoring or engine starting operations, the switch must be in the motor position. When the engine is operating and applying power so that the dynamometer is in an absorption mode, the switch may be placed in the absorb position and any engine failure which causes loss of power output will cause automatic system shutdown and prevent damage to the engine which might be caused when the dynamometer reverts to the motoring mode.

6.0 SHUTDOWN PROCEDURE

6.1 H_2O_2 engine may be shut down by operating H_2/N_2 and O_2/N_2 switches in proper sequence and purging with N_2.

6.2 Dynamometer may be shut down by pressing "Stop" button at top, right corner of main console.

6.3 System may be secured by reverting to original conditions of paragraph one and turning all circuit breakers and power switches "Off".

APPENDIX B

INSPECTION SYSTEM DESCRIPTION

INSPECTION SYSTEM DESCRIPTION

INSPECTION PLANNING

In order to assure that material is manufactured according to specification requirements, each processing instruction is reviewed and approved by Quality Assurance. An Inspection Instruction is prepared which reflects the characteristic to be inspected and the acceptance quality level.

QUALITY ASSURANCE RECORDS

The Quality Assurance Department maintains documentation of inspection and testing performed during the various phases of manufacture, as well as recurring rejections and corrective action. This information is available to NASA Representatives and other departments. The procedure which describes the method of compiling and maintaining these records is the Vickers Quality Assurance Manual SPI 105.

DRAWING AND CHANGE CONTROL

Procedures have been established which ensure that pertinent drawing, manufacturing instruction, specification, test procedure, purchase order and contract change information is available to the Inspection Department for determination of conformance. Provisions have been made for issuance of new instructions in the event of a change in requirements. These instructions contain provisions for handling material currently in process. The system is described in SPI 401.

TOOL CONTROL

A tool control number is assigned to all fixtures that are used in the manufacture or assembly of the product. The tools are inspected in accordance with the applicable blueprint. Those tools which are used to determine conformance of the product to specification requirements are reinspected at established intervals by the Tool and Gage Inspector. SPI 203 describes the method for the inspection and use of tooling.

NONCONFORMING SUPPLIES

A system has been established for reporting material and parts which due to improper or faulty processing, treatment, handling, or work operations, fail to conform to product specifications.

When such parts or materials are detected, they are immediately identified as discrepant and removed from the manufacturing process for analysis and review by a Material Review Board (MRB). During the period between detection and review, the material is segregated to prevent its accidental use. The Board consults with other departments as necessary to determine all functional and quality requirements in order to make effective disposition.

The Material Review Board is organized and functions in accordance with Air Force Specification Bulletin NR-515. Permanent members consist of a Quality Assurance representative, an Engineering representative, and the resident Air Force Quality Control Representative.

CORRECTIVE ACTION

When discrepancies are detected during manufacturing, corrective action must be taken by the department responsible for the discrepancy prior to resuming production. A representative of Preliminary Review or the Quality Assurance Representative on the MRB is responsible for assuring that the corrective action has been taken.

Discrepancies detected at other stages of production for which the proper corrective action is not immediately evident, are subjected to analysis to determine the probable cause of the discrepancy. Based on this analysis, corrective action is initiated and documented. Subsequent followup of corrective action is taken by the Quality Assurance representative on the MRB as required. Instructions which describe the manner in which corrective action is obtained are included in SPI 200.

APPENDIX C

FAILURE REPORT AND SUMMARY SHEETS

ENGINE FAILURE MODES

1. Oxygen injector

   A. Broken flex pivot
   B. Static seal leak
   C. Bushing to shaft seizure
   D. Leak spring retainer deformed
   E. Flame plated valve worn
   F. Rocker shaft Brinelled
   G. Rocker shaft galled

2. Engine

   A. H_2 valve assembly leakage
   B. Catalyst plug gasket leak
   C. H_2 valve retainer ring broke
   D. Piston dome retaining screw broke
   E. Piston seized in cylinder
   F. Top cylinder-to-cooling jacket "O" ring failure
   G. Copper, head-to-cylinder gasket

SHEET NO. 1 of 4

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2787
MARK I H_2 - O_2 ENGINE MODEL EA-1570-515

Note: 1. Initial and Date Items you fill in. 2. Rework SK No.'s can be used as Serial No.'s.

Failure No.	Data Sheet No. Time & Date of Failure	Part Name	Part No. & Serial No.	Description of Failure (The Part Condition)	Description of Conditions (Active on Part prior to Failure)	Failure Mode No.	Cumulative Time on Part in Minutes	Action Taken
1	D.S. 18	O_2 Injector Flex Pivot	X610104	Broken Flex Pivot	Engine shut down due to tendency of oxygen valve to stick open.	1A	70 Cold 41 Hot	New flex pivot installed
2	D.S. 21	O_2 Injector Flex Pivot	X610104	Broken flex pivot	Engine cylinder head temperature was low and could not be increased.	1A	257 Cold 75 Hot	New flex pivot installed; poppet refinished and lapped; seat guide lapped.
3	D.S. 23	O_2 Injector Face Seal	X610113	Leaking haskel seal	Engine stopped because O_2 ΔP gauge showed increased flow.	1B		New seal installed.
4	D.S. 23	O_2 Injector Flex Pivot	X610104	Flex pivot broken	Cylinder head temperature could not be raised to 1400°F and O_2 flow fluctuated excessively.	1A	88 Hot	Pivot removed and replaced with a new stainless flex pivot.
5	D.S. 27, 28-10-12-63	O_2 Injector Flex Pivot	X610104	All three bands of O_2 injector flex pivot broken.	Engine stopped when O_2 flow fluctuated excessively.	1A	142 Hot	New flex pivot installed
6	10-18-63	O_2 Injector Bushing	X611376	Flame plated bearing seized in bushing. Bushing had started to come out of body.	Engine started and O_2 flow increased to full flow.	1C	68 Cold 1 Hot	Bushing pressed back into body.
7	D.S. 33	O_2 Injector Bushing	X611376	O_2 Injector was sticking. Flame plated bushing and shaft seized together.	Engine stopped when O_2 flow became erratic.	1C	37 Hot	Bushing honed out for an 0.0008 to 0.001 clearance and counter-bored to prevent end of shaft from rubbing on bushing.
8	11-1-63	O_2 Injector Retainer	X611378	Leaf spring had been deformed around end of valve.	Normal inspection of O_2 injector.	1D	247 Hot	New retainer installed.

SHEET NO. 2 of 4

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2787
MARK I H_2 - O_2 ENGINE MODEL EA-1570-515

Note: 1. Initial and Date Items you fill in. 2. Rework SK No.'s can be used as Serial No.'s.

Failure No.	Data Sheet No. Time & Date of Failure	Part Name	Part No & Serial No.	Description of Failure (The Part Condition)	Description of Conditions) (Active on Part prior to Failure)	Failure Mode No.	Cumulative Time on Part in Minutes	Action Taken
9	11-13-63	O_2 Valve	X611402	Some flame plated material came off seat area.	Test stand used for test valve run using cold gas.	1E	68 Cold	Valve sent to NASA Lewis for examination.
10	11-16-63	O_2 Injector Retainer	X611378	Leaf spring had been deformed around end of valve.	Normal inspection of O_2 injector.	1D	232 Hot	New retainer installed.
11	11-19-63	H_2 Valve Assembly	X611414	Seals in H_2 valve assembly leaking.	Engine stopped when flames were observed coming from H_2 valve assembly.	2A	230 Hot	New H_2 valve assembly seals installed. One copper seal made. H_2 manifold brazed.
12	12-7-63	O_2 Injector Valve	X611402	Some flame plated material came off seat area.	Test stand used for test valve run using cold gas.	1E	30 Cold	Valve to be returned to Linde Co. for examination and recommendation.
13	11-21-63	H_2 Valve Assembly	X611414	Seals in H_2 valve assembly leaking.	Engine stopped when flames came out of H_2 valve assembly.	2A	6 Hot	New seals installed.
14	11-23-63	O_2 Injector Valve	X611402	Excessive wear on guide area of valve (flame plated).	Engine stopped when O_2 injector could not be controlled.	1E	300 Hot	Valve sent to NASA Lewis for metallurgist examination.
15	12-12-63	O_2 Injector Retainer	X611378	Leaf spring retainer deformed around end of valve.	Normal inspection of injector.	1D	552 Hot	New retainer installed.
16	12-12-63	H_2 Valve Assembly Ring	X610171	H_2 valve ring worn through.	Normal disassembly for inspection of O_2 injector.	2C	819	New ring installed.
17	12-20-63	H_2 Valve Assembly		H_2 valve assembly leakage.	Engine stopped when fire came out of top seal of H_2 valve assembly. Note: The 3 screws had loosened and may have caused the leak.	2A	41 Hot	New seals installed.

SHEET NO. 3 of 4

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2787
MARK I H_2 - O_2 ENGINE MODEL EA-1570-515

Note: 1. Initial and Date Items you fill in. 2. Rework SK No.'s can be used as Serial No.'s.

Failure No.	Data Sheet No. Time & Date of Failure	Part Name	Part No. & Serial No.	Description of Failure (The Part Condition)	Description of Conditions) (Active on Part prior to Failure)	Failure Mode No.	Cumulative Time on Part in Minutes	Action Taken
18	1-17-64	Piston Dome Retaining Screw	X611408	Piston dome retaining screw failed in tension allowing piston dome to jam between piston and cylinder head, thus causing the engine to stop abruptly.	Engine had been run hot for 43 minutes when a strange noise started followed by an abrupt stop of the engine.	2D	540Cold 376 Hot	Use new piston design now being fabricated. Interim Corrective Action: 1. Reduce installing torque from 80in-lb to 50in-lb. 2. Design rework to reduce or eliminate leakage and to increase screw diameter.
19	2-6-64	O_2 injector rocker shaft	X610099	Rocker shaft was Brinelled by needle bearings.	Engine had been run for 14 hours endurance run.	1F	2267	Evaluate oilite bushing bearing.
20	3-12-64	O_2 injector rocker shaft	X610099	Rocker shaft was galled by lower iron oilite bearings.	Engine did not run steady and O_2 injector lift had dropped.	1G	41 Hot 25 Cold	Shaft polished and hardened. Alternate bearing materials and shaft finishes to be evaluated.
21	3-30-64	Piston Assembly	X612030	Piston seized to cylinder due to local thermal expansion of piston top nearest O_2 inlet port.	Head insert deflecting O_2 axially down cylinder onto piston.	2E	1 Hot 415Cold	Increase piston-to-cylinder clearance and reposition head insert.
22	3-31-64	Piston Assembly	X612030	Piston rings and top of piston scored cylinder and started to seize in cylinder.	Piston to cylinder and ring gap clearance still insufficient.	2E	3 Hot 420 Cold	Further increase piston-to-cylinder clearance and increase ring gap.
23	4-10-64	O Ring	X612049	"O" Ring leaked Dowtherm at top of cylinder.	Cylinder wall temperature was higher than expected.	2F	126 Hot	New "O" Rings installed. Viton "A" 'O'-Rings Ordered

VICKERS INCORPORATED
FAILURE REPORT & SUMMARY SHEET
FOR NASA CONTRACT NASA 3-2787
MARK I H_2 - O_2 ENGINE MODEL EA-1570-515

Note: 1. Initial and Date Items you fill in. 2. Rework SK No.'s can be used as Serial No.'s.

Failure No.	Data Sheet No. Time & Date of Failure	Part Name	Part No. & Serial No.	Description of Failure (The Part Condition)	Description of Conditions (Active on Part prior to Failure)	Failure Mode No.	Cumulative Time on Part in Minutes	Action Taken
24	4-13-64	O Ring	X612049	2F		2F	42 Hot	New "O" Rings installed. Viton "A" 'O'-Rings ordered
25	4-14-64	O Ring	X612049	2F		2F	22 Hot	SK 15822 Viton O Rings installed.
26	4-16-64	Head Seal	X612207	Head seal leaked during run	Flame came out from under head.	2G	22 Hot	New seal installed
27	4-21-64	O Ring	SK 15822	2F		2F	92 Hot 115 Cold	New O Ring installed
28	4-22-64	O Ring	SK 15822	2F		2F	56 Hot	New O Ring installed
29	4-27-64	O Ring	SK 15822	2F		2F	143 Hot	New O Ring installed
30	4-28-64	O Ring	SK 15822	2F		2F	19 Hot	New O Ring installed
31	4-28-64	Head Seal	X612207	2G	Flame came out from under head	2G	19 Hot	New seal installed